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Hybrid Meson Structure at COMPASS

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Abstract

Objectives and Significance:

We describe a pion physics program attainable with the CERN COMPASS spectrometer, involving tracking detectors and an electromagnetic calorimeter. COMPASS can realize state-of-the-art pion beam hybrid meson and meson radiative transition studies. We review here the physics motivation for this program. We describe the beam, detector, trigger requirements, and hardware/software requirements for this program. The triggers for all this hybrid meson physics can be implemented for simultaneous data taking.

We will investigate hybrid meson production via pion-photon Primakoff and pion-Pomeron diffractive interactions. We will determine new properties of quark-antiquark-gluon hybrid mesons, using unique production methods, to improve our understanding of these exotic mesons.

Methodology:

The CERN COMPASS experiment uses 100-280 GeV beams (μ, π), and magnetic spectrometers and calorimeters, to measure the complete kinematics of pion-photon and pion-Pomeron reactions. The COMPASS experiment is currently under construction, and scheduled to begin data runs in 2001. We carry out simulation studies to optimize the beam, detector, trigger, and hardware/software for achieving high statistics data with low systematic uncertainties in the hybrid meson component of this program. We will improve previous Primakoff Hybrid studies by three orders of magnitude. We implement special detectors and triggers for hybrid meson production reactions. We propose to prepare for these COMPASS pion beam hybrid studies by setting up with muon beam tests.

1. Description of Subject:

The COMPASS physics programs [1] include studies of pion-photon Primakoff and pion-Pomeron diffractive interactions using 100-280 GeV/c negative pion beams in dedicated data runs. Hybrid mesons can be studied in this way, and can provide significant tests of QCD predictions. COMPASS Primakoff planning studies were described in recent workshop proceedings [2, 3, 4], and at COMPASS collaboration meetings.

1.1 Hybrid Mesons

The hybrid ($q\bar{q}g$) mesons, along with glueballs (gg) are some of the most interesting consequences of the non-Abelian nature of QCD. Detection of these exotic states is a long-standing experimental puzzle. The most popular approach for hybrid searches is to look for the 'oddballs'—mesons with quantum numbers not allowed for ordinary $q\bar{q}$ states. For Primakoff/diffractive production, the outgoing mesons preserve the charge of the incoming beam, i.e. $I = 1$ for the resonances under study. Then, the 'oddball' mesons for $J \leq 2$ come in the following variety:

$I^G(J^{PC})$	'Oddball'
$1^+(0^{--})$	ρ_0
$1^+(0^{+-})$	b_0
$1^-(1^{-+})$	π_1
$1^+(2^{+-})$	b_2

Barnes and Isgur first discussed hybrid meson properties, and more recently in the flux-tube model [5, 6]. In the flux-tube model, the mass of the lightest gluonic hybrid is predicted be around 1.9 GeV, with the quantum numbers of $J^{PC} = 1^{-+}$. Close and Page [7] predict that such a gluonic hybrid should decay into the following channels:

$b_1\pi$	$f_1\pi$	$\rho\pi$	$\eta\pi$	$\eta'\pi$
170	60	$5 \rightarrow 20$	$0 \rightarrow 10$	$0 \rightarrow 10$

where the numbers refer to the partial widths in MeV. According to them, its total width must be larger than 235-270 MeV, since the $s + \bar{s}$ decay modes were not included. Recent updates on hybrid meson structure are given in Refs. [8, 9, 10]

From more than a decade of experimental efforts at IHEP [11, 12, 13], CERN [14], KEK [15], and BNL [16], several hybrid candidates have been identified. More recently, new information came from the BNL E852 experiment [16], which studied the $\pi^- p$ interaction at 18 GeV/c. They reported two $J^{PC} = 1^{-+}$ resonant signals at masses of 1.4 and 1.6 GeV in $\eta\pi^-$ and $\eta\pi^0$ systems, as well as in $\pi^+\pi^-\pi^-$, $\pi^-\pi^0\pi^0$, $\eta'\pi^-$ and $f_1(1285)\pi^-$. Also, a VES group [13] has published analyses of $\eta\pi^-$, $\eta'\pi^-$, $f_1(1285)\pi^-$, $b_1(1235)\pi^-$ and $\rho\pi^-$ systems produced in π^-Be interactions at 37 GeV/c. VES sees the $J^{PC} = 1^{-+}$ wave clearly in all channels, and they report an indication of a resonance at 1.6 GeV. It is striking that the VES phase motion of the 1^{-+} wave in $\eta\pi^-$ shows a rise at 1.4 GeV, identical to that of the BNL E852 data. The most recent information on the 1.4-GeV state comes from two analyses by the Crystal Barrel collaboration on the $\bar{p}p$ and $\bar{p}n$ annihilations at rest into $\pi\pi\eta$ [17],[18]. Their observed masses and widths are consistent with those of BNL E852. VES reports that the ratio of $\eta'\pi$ to $\eta\pi$ P-waves at 1.4 GeV is low, while that at 1.6 GeV is high. This is considered as evidence that the hybrid nature of the exotic wave at 1.6 GeV is gluonic; i.e., its constituents are $q + \bar{q} +$ gluon, where q stands for light nonstrange quarks.

The partial-wave analysis (PWA) of systems such as $\eta\pi$ or $\eta'\pi$ in the mass region below 2 GeV requires care and experience. This is so because (1) this region is dominated by the strong 2^+ 'background' (a_2 resonance), and (2) that the PWA may give ambiguous results [12] for the weaker 1^{-+} wave. For Primakoff production, the hybrid production cross section may increase relative to the a_2 state, considering the estimated radiative widths. These are $\Gamma(a_2 \rightarrow \pi\gamma) = 300$ keV, and $\Gamma(\pi_1 \rightarrow \pi\gamma) \approx 90 - 540$ keV, as discussed in Section 2. Therefore, the PWA uncertainties for the 1^{-+} wave will be different and may even improve. The problem generally is that the PWA of the $\eta\pi$ system must take into account S-, P- and D-waves, and the number of observables is not sufficient to solve all equations unambiguously. The strength and phase ambiguities as a function of mass of different partial wave solutions are discussed in ref. [12]. However, in certain experimental situations, the ambiguous solutions have relatively little impact on a particular exotic wave under study—such a situation seems to be the case with the BNL E852 data. In addition, it has been shown [19] that certain other assumptions, e.g., the rank-one condition, can be removed in a systematic study in which the mass-dependence of each partial wave is introduced explicitly into the analysis.

The masses and widths of $\pi_1(1400)$ meson in the decay channel $\pi\eta$ are summarized in Table I.

Table I: Parameters for $\pi_1(1400) \rightarrow \eta\pi$

Expt.	Mass(MeV)	Width(MeV)
KEK	1323.1 ± 4.6	143.2 ± 12.5
BNL('94)	$1370 \pm 16 {}^{+50}_{-30}$	$385 \pm 40 {}^{+65}_{-105}$
BNL('95)	$1359 {}^{+16}_{-14} {}^{+10}_{-24}$	$314 {}^{+31}_{-29} {}^{+9}_{-66}$
CB	$1400 \pm 20 \pm 20$	$310 \pm 50 {}^{+50}_{-30}$
CB	1360 ± 25	220 ± 90

At a recent Workshop on Hadron Spectroscopy [20], the VES collaboration presented the results of a coupled-channel analysis of the $\pi_1(1600)$ meson in the channels $\rho\pi$, $\eta'\pi$ and $b_1(1235)\pi$. Their results are consistent with the BNL results, as seen in Table II.

Table II: Parameters for $\pi_1(1600)$ Decay

Expt.	Mass(MeV)	Width(MeV)	Decay
BNL	$1593 \pm 8 {}^{+20}_{-47}$	$168 \pm 20 {}^{+150}_{-12}$	$\rho\pi$
BNL	1596 ± 8	387 ± 23	$\eta'\pi$
VES	1610 ± 20	290 ± 30	$\rho\pi$,$\eta'\pi$,$b_1\pi$

For both BNL E852 and VES data, it is not known what Regge exchanges are responsible for the production of the $J^{PC} = 1^{-+}$ exotic states at 1.4 and 1.6 GeV, Both the $a_2(1320)$ and the exotic waves are produced via natural-parity exchanges which include the Pomeron.

If Pomeron exchange is indeed responsible the production, then diffractive production in COMPASS can provide an additional handle with which to tackle the study of exotic waves.

One can succinctly summarize the situation as follows: a production of the wave $I^G(J^{PC}) = 1^-(1^{-+})$ is dependent on the strength of the $\pi\rho$ decay modes in the case of the Primakoff production, whereas in diffractive production the relative strengths depend on the supposed decay modes $\pi_1(1400)\pi$ and $\pi_1(1600)\pi$ of the tensor glueball (2^{++}), since the Pomeron is thought to be on the Regge trajectory corresponding to the tensor glueball with a presumed mass around 2 GeV. Corresponding to the glueball decay $G(2^{++}) \rightarrow \pi^+ Hybrid$, one expects diffractive production via $\pi^- G(2^{++}) \rightarrow Hybrid$. This is an additional strong advantage of the COMPASS hybrid meson study. We can look forward to two complementary production modes of exotic mesons, increasing our chance for achieving a decisive advance on our understanding of the meson constituents. Finally, the E852 collaboration finds preliminary evidence of a third exotic meson at around 1.9 GeV. The search for this state as well as others can continue, with exciting new results anticipated. In summary, COMPASS can move into a forefront of hadron spectroscopy, by studying Primakoff and diffractive production of nonstrange light-quark hybrid mesons in the 1.4-2.5 GeV mass region, including all the hybrid candidates from previous studies.

1.2 Radiative Transitions

Radiative decay widths of mesons and baryons are powerful tools for understanding the structure of elementary particles and for constructing dynamical theories of hadronic systems. Straightforward predictions for radiative widths make possible the direct comparison of experiment and theory. The small value of branching ratios of radiative decays makes them difficult to measure directly, because of the large background decay π^0s from strong decays. Studying the inverse reaction $\gamma + \pi^- \rightarrow M^-$ provides a relatively clean method for the determination of the radiative widths. Very good tracking resolution is needed (and available through silicon strip detectors) to measure initial and final state momenta, and to thus exhibit the Primakoff signal at small momentum transfers, where the electromagnetic processes dominate over the strong interaction.

In COMPASS, we will study radiative transitions of incident mesons to higher excited states. We will obtain new data ([3]) for radiative transitions leading from the pion to $a_1(1260)$, $a_2(1320)$, and ρ mesons. The previous Coulomb field measurements of the $a_1(1260) \rightarrow \pi\gamma$ width ([21]) is 0.64 ± 0.25 MeV; of the $a_2(1320) \rightarrow \pi\gamma$ width [22] is 0.30 ± 0.06 MeV; and of the $\rho \rightarrow \pi\gamma$ width ([26]) is 60 to 81 keV. We will obtain independent and significantly higher precision data and statistics for these and higher resonances. This will be valuable in order to allow more meaningful comparisons with theoretical predictions, and as a normalization of the Hybrid meson studies.

1.3 Experimental Requirements

We consider the beam, target, detector, and trigger requirements for hybrid meson production and detection with minimum background contamination.

1.3.1 Monte Carlo Simulations

We carry out Monte Carlo simulations with HYBRID, an event generator adapted to COMPASS for Hybrid meson physics studies. For hybrid mesons, simulations [24] were carried out for the FNAL SELEX apparatus, a low rate forward spectrometer, otherwise very similar to COMPASS. SELEX however did not obtain quality hybrid physics data. We base our initial planning on the previous FNAL Primakoff experiments and on available SELEX simulations, while pursuing further simulations for COMPASS [25].

1.3.2 Beam Requirements

A beam Cherenkov detector (CEDARS) far upstream of the target provides $\pi/K/p$ identification. We will take data with both positive and negative beams. We may use a 280 GeV beam, the highest energy available at COMPASS, because Hybrid meson Primakoff production cross sections increase with increasing energy, and because the calorimeter acceptances are higher at the highest energy. Beam rates lower than the 40 MHz COMPASS design rate are planned for initial setup studies, in which many of the COMPASS systems (DAQ, detectors, etc.) must be implemented. We base our count rate estimates on beam intensities of 10 MHz (20×10^7 particles in a 2 second spill with a total cycle time of 14.8 seconds).

1.3.3 Target and Target Detectors

We mainly veto target break-up events by positioning veto scintillators around the target. We also veto target break-up events by selecting multiplicity 1 or 3 events in downstream hodoscopes H1 and H2 (Fig. 2) at the trigger level, and by selecting low-t events in the off-line analysis. Before and after the target, charged particles are tracked by high resolution tracking detectors. We achieve good angular resolution for the final state charged particles by minimizing the multiple scattering in the targets and detectors. The Primakoff targets will be Pb of 1% interaction length = 2 g/cm^2 =0.30 radiation length, and other targets such as Cu of similar and also smaller radiation length. The beam and outgoing pion multiple Coulomb scattering in the target gives an rms angular resolution of about 40 μrad.

1.3.4 The Magnetic Spectrometer and the t-Resolution

The incoming beam momentum is measured with upstream SPS detectors. The final state pion and γ momenta are measured with good resolution in downstream COMPASS magnetic spectrometers and in the photon calorimeter, respectively. Via the measurement of incident and final state momenta, we obtain a precise determination of the square of the four momentum transfer t to the target nucleus. The small transverse momentum kick p_T to the target and t are related by $t = p_T^2$. We aim for a p_T resolution or about 10 MeV/c, corresponding to resolution $\Delta t = 2 \times 10^{-4}$ GeV^2 for production of a 2 GeV Hybrid. This goal is based on the need to minimize contributions to the Coulomb Primakoff data from diffractive production. A peak in the t distribution at low t provides the main signature of the Primakoff process, and the means to separate Primakoff from diffractive scattering. The Pb diffractive data for example falls as $\exp(-t/0.0025)$ with t expressed in GeV^2. Our t-resolution goal is then about a factor of 10 smaller than the slope in t observed for diffractive data on a Pb target. This goal is clearly achievable, as one may see from the t distributions measured at a low statistics but high resolution experiment for $\pi^- \rightarrow \pi^-\pi^0$ [26] and $\pi^- \rightarrow \pi^-\gamma$ [27] Primakoff scattering at 200 GeV at FNAL. The t distribution of the $\pi^- \rightarrow \pi^-\gamma$ [27] data agrees well with the Primakoff formalism out to t = 10^{-3} GeV^2, which indicates that the data are indeed dominated by Coulomb production.

1.3.5 The Photon Calorimeter ECAL2

The momentum kicks of the two COMPASS magnets are set *additive* for maximum deflection of the beam from the zero degree (neutral ray) line. This maximizes the distance from the zero degree line to the beam hole in ECAL2 (located about 30 meters from target), and attains an acceptable distance of at least 10 cm between the zero degree line and the deflected beam position at ECAL2 for the proposed 280 GeV beam energy. The hole size and position must be optimized to minimize the number of pions hitting ECAL2 blocks at the hole perimeter. The Primakoff γ's are centered around the zero degree line, and a good γ measurement requires clean signals from 9 blocks, centered on the hit block. The ADC electronic readouts for these blocks have been designed and are being built.

As can be seen in Fig. 1, COMPASS needs to also detect ηs for the hybrid study. The two γs from η decay have half-opening angles $\theta^h_{\gamma\gamma}$ for the symmetric decays of $\theta^h_{\gamma\gamma} = m/E_\eta$, where m is the mass ($\eta$) and E_η is the η energy. Opening angles are somewhat larger for asymmetric decays. In order to catch about 50% of the decays, it is necessary to subtend a cone with double that angle, i.e. $\pm 2m/E_\eta$, neglecting the angular spread of the original ηs around the beam direction. Consider an ECAL2 γ detector with a circular active area with 2 m diameter. Consider the $\pi\eta$ channel. For an ECAL2 of 1 m radius at 30 m from the target, ηs above E_η=33 GeV are therefore accepted. At half this energy, the acceptance practically vanishes. The acceptance of course depends on the Hybrid mass, mostly between 1.4 and 2.5 GeV for the planned COMPASS study. Detailed Monte Carlo studies are in progress for the different possibly Hybrid decay modes, for a range of assumed masses. One also must consider the efficiency that the two γs are sufficiently separated, to be able to get a position and energy measurement for each of them. For the πf_1 channel, with for example $f_1 \to \pi\pi\eta$, the ηs will have low energy, and therefore large gamma angles. To maintain good acceptance for low energy ηs, the ECAL2 diameter should be 2 m or more.

Primakoff physics requires a very good position and energy resolution of photon calorimeters. The ECAL2 blocks will have their gains well matched, and their analog signals will be electronically summed and discriminated to provide a trigger signal on minimal energy deposit. For the precise monitoring of the energy calibration of the photon calorimeters, COMPASS will use a dedicated laser system [28].

1.3.6 The Primakoff Trigger

We design [2, 3, 4] the COMPASS Primakoff/Diffractive hybrid meson trigger to enhance the acceptance and statistics, and also to yield a trigger rate closer to the natural rate given by the low hybrid cross sections. The trigger should suppress the beam rate by a factor 10^3-10^4 or better, while also achieving high acceptance. The resulting rate will be significantly lower than the maximum of 10^5 per second DAQ limit in COMPASS [29]. We veto target break-up events via veto scintillators around the target. For hybrid meson physics, the trigger uses the characteristic hybrid decay pattern: one or three charged hadrons with gamma hits, or three charged hadrons and no gamma hits. The hybrid trigger [2, 3, 4] for the $\pi\eta$ hybrid decay channel (charged particle multiplicity =1) is based on a determination of the pion energy loss (via its characteristic angular deflection), correlated in downstream scintillator hodoscopes stations (H1 versus H2) with the aid of a fast matrix chip, as shown in Fig. 2. The chip was designed and already tested for the analogous COMPASS energy-loss trigger for the muon beam runs.

We will also test alternative and/or complementary trigger concepts. We have already successfully carried out trigger tests at the CERN test channels, and made reports at COMPASS collaboration meetings. For example, the non-interacting beam may be detected and vetoed by the Beam Kill veto trigger detectors BK1/BK2, which follow the pion trajectory, as shown in Fig. 2. This Beam Kill idea must be tested. It requires very fine segmentation for the BK1 and BK2 detectors to be able to accept a 40 MHz beam rate, and it requires very high efficiency since detector inefficiencies in killing the beam can lead to artificially high trigger rates. We will test the energy loss trigger described above, with and without adding the beam kill trigger capability. Depending on the results, we will make a decision on implementing the BK detectors. Even if finally not implemented for the data taking, tests with the beam killer detectors will be valuable for setting up the energy loss trigger.

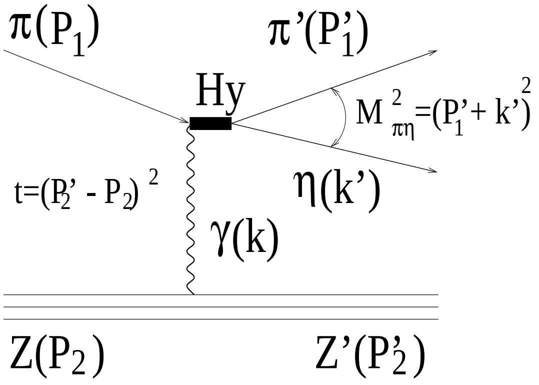

Figure 1: The Primakoff γ-pion Hybrid production process and kinematic variables (4-momenta): P1, P1$'$ = for initial/final pion, P2, P2$'$ = for initial/final target, k = for initial γ, k$'$ = for final η.

We foresee a three-level Primakoff trigger scheme: T0 = beam definition, T1 = event topology, T2 = online software filter. T0 is a fast logical signal that includes upstream CEDARS Cherenkov detectors for beam PID. T1 is a downstream coincidence between scintillation H1-H2 hodoscope signals, with charged particle multiplicity 1 (π^-) or 3 (2 negative, one positive) conditions. T2 is an intelligent software filter, placed in the DAQ stream after the event builder, which counts the number of reconstructed track segments upstream and downstream from the target, and also sets cuts on event quality characteristics (goodness of kink or vertex reconstruction, cuts on the t-distribution, etc.).

As an example, for M$_{HY}$ near 1.5 GeV, HY $\rightarrow \pi^-\eta$ events can have 40-235 GeV pions at angles larger than 0.5 mrad, close to the non-interacting 280 GeV beam, and two forward photons at angles less than 30 mrad. Pions with energy lower than 40 GeV are blocked by the magnet yokes. The kinematic variables for the HY $\rightarrow \pi^-\eta$ Primakoff process are shown in Fig. 1. A virtual photon from the Coulomb field of the target nucleus interacts with the pion, a Hybrid meson is produced and decays to $\pi^-\eta$ at small forward angles in the laboratory frame, while the target nucleus (in the ground state) recoils coherently with a small transverse kick p$_T$. The peak at small target p_T used to identify the Primakoff process is measured offline using the beam and vertex silicon detectors. For diffractive processes, the beam pion interacts with an exchanged Pomeron.

The T1 trigger scheme (for photon-pion reactions with one charged pion and two photons in the final state) for an assumed 280 GeV pion beam is shown in Fig. 2. BK1 and BK2 are small scintillator hodoscopes; while H1 and H2 are larger scintillator hodoscopes with larger segmentation, all in the beam bend plane. The beam passes through holes in H1 and H2. An anticoincidence in the "beam" region of BK1 and BK2 can be used to veto non-interacting beam pions. According to Monte Carlo simulation, a 30 GeV energy loss condition achieves beam suppression with 99.8% efficiency, while maintaining 100% efficiency for all Primakoff scattered pions with momenta at least 30 GeV/c lower than the beam momentum. For a trigger that accepts Primakoff scattered pions with momenta at least 45 GeV/c lower than the beam momentum, beam suppression is of course yet better. For the case of one charged pion in the final state, we require an ECAL2 γ signal above 45 GeV in coincidence with a final-state pion in the energy range $(40 - 235$ GeV). The threshold for the ECAL2 γ signal is set to match the kinematic region of Primakoff scattered pions that satisfy the 45 GeV energy loss trigger condition. The BK1 and BK2 hodoscope sizes are optimized for beam pions. We measure the energy loss of the π^- via characteristic angular deflections, correlated with hits in the H1 versus H2 hodoscopes. A fast matrix chip is used for this purpose, as developed for the standard muon energy-loss trigger in planned COMPASS studies of gluon polarization

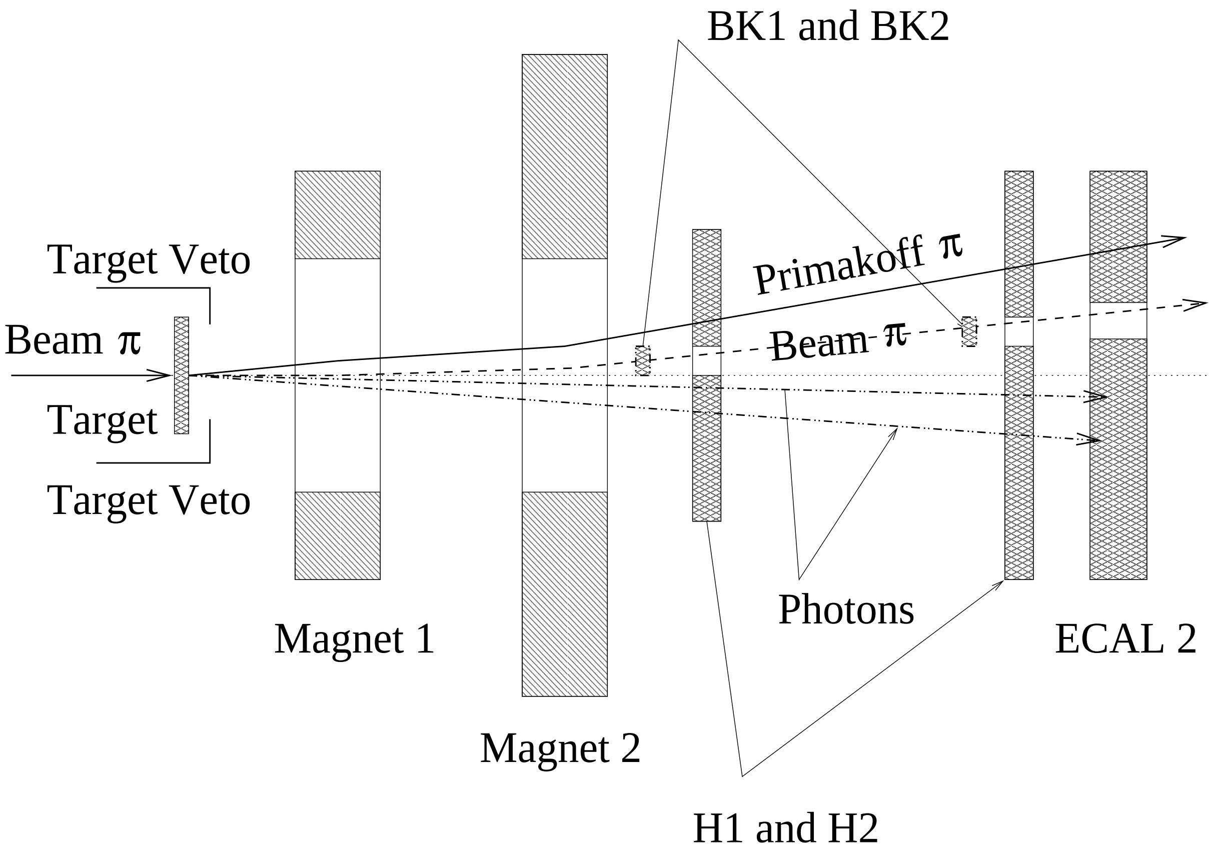

Figure 2: Detector layout for the COMPASS Primakoff Hybrid trigger. BK1,BK2=beam killer system, H1,H2=hodoscope system for charged particle detection, ECAL2=second photon calorimeter.

in the proton. A coincidence based on H1/H2 hodoscope correlations, with multiplicity=1 condition, where the H1-H2 line projects back to the target beam spot, is used to trigger on the Primakoff decay pion in the $\pi^-\eta$ channel.

This trigger configuration for Primakoff scattering strongly suppresses backgrounds associated with both non-interacting beam particles and those involving nuclear interaction of pions in the target and in COMPASS apparatus. The Primakoff trigger design suppresses the beam rate by up to a factor 10^3-10^4, achieving high acceptance efficiency for events versus the important kinematic variables. The diffractive cross sections leading to the $\pi^-\pi^0\pi^0$ and $\pi^-\pi^-\pi^+$ final states are large. Since we aim to also observe diffractive production, we may need to prescale the triggers for such strong channels.

We will study the acceptance of this trigger in COMPASS for the $\pi^-\eta$ hybrid meson decay mode using our MC code HYBRID [25], which generates Primakoff pion-photon hybrid meson production interactions, with realistic beam phase space. We will also study the πf_1 and other decay mode acceptances with HYBRID. The T1 trigger scheme for the πf_1 decay channel is based on part or all of the following: a multiplicity = 3 condition, condition of one positive and 2 negative tracks, condition that one can find 3 H1-H2 track lines that all point back to the small beam spot on target, condition that the total energy associated with the tracks and γ energy is of order 280 GeV. How many of these conditions we include depends on how low a trigger rate we may easily achieve with minimum bias. For the case of three charged particles and also γs in the final state, the trigger rate is lower than the beam rate by a lower factor than for $\pi\eta$, but still lower than the COMPASS DAQ limit. In addition, the H1 and H2 hodoscope may veto charged particles with larger angles than expected for all the hybrid decay channels, and also events with multiplicity higher than 3.

Minimum material (radiation and interaction lengths) in COMPASS will give a clean (low background) trigger. This is so since γs may arrive at ECAL2 with minimum interaction losses, while producing minimum background interactions. That is, it is best to use a minimally instrumented COMPASS apparatus for Primakoff and Diffractive hybrid meson structure studies.

2. Objectives and Expected Significance

COMPASS can contribute significantly to the further investigation of hybrids by studying Primakoff and Diffractive production of $I^G(J^{PC}) = 1^-(1^{-+})$ 'π_1'—or more generally $I^G(J^{PC}) = 1^+(0^{+-})$ 'b_0' or $I^G(J^{PC}) = 1^+(2^{+-})$ 'b_2'—hybrids. The possibilities for Primakoff production of the π_1 with energetic pion beams, and detection via different decay channels, were discussed previously in Refs. [4, 24], and Monte Carlo simulations for this physics are in progress for COMPASS [25]. The experiment will be run with the COMPASS spectrometer, consisting of the spectrometer magnets, the central tracking detectors, the ECAL2 calorimeter, and a relatively simple trigger. The COMPASS Primakoff trigger will allow observation of the π_1 via the $\eta\pi^-$ decay mode. With a relative P-wave (L=1), the $\eta\pi^-$ system has $J^{PC} = 1^{-+}$. The other decay channels of π_1 may be studied simultaneously in COMPASS by relatively simple particle multiplicity triggers (three charged particles in final state, etc.).

We make rough estimates of the statistics attainable for hybrid production in the COMPASS experiment. Monte Carlo simulations in progress will refine these estimates. We assume a 125-1250μb Hybrid meson production cross section per Pb nucleus (near 1.5 GeV mass). This estimate is based on two considerations. First, a straightforward application of VDM with $\rho - \gamma$ coupling $g^2_{\rho\gamma}/\pi$=2.5, gives a width of $\Gamma(\pi_1 \to \pi\gamma)$ = 75-750 keV for a 1.5 GeV Hybrid, assuming $\Gamma(\pi_1 \to \pi\rho)$= 10-100 MeV, a range corresponding to 3.3-33% of the claimed 1.5 GeV hybrid width. Integrating the Primakoff Hybrid production differential cross section for a 280 GeV pion beam with this $\Gamma(\pi_1 \to \pi\gamma)$ width gives 125-1250 μb. Second, a FNAL E272 measurement indicated (but with high uncertainty) that $\Gamma(\pi_1 \to \pi\gamma) \times BR(\pi_1 \to \pi f_1) \approx 250$ keV for a 1.6 GeV Hybrid candidate. This would be consistent with the above maximum VDM $\Gamma(\pi_1 \to \pi\gamma)$ estimate for $\mathrm{BR}(\pi_1 \to \pi f_1)$ = 33%. With a total π inelastic cross section per Pb nucleus of 0.8 barn, the Primakoff Hybrid production event rate R (events per interaction) is then R= 1.6-16 $\times 10^{-4}$.

In four months of running, we obtain 1.4×10^{13} beam pions. With a 1% interaction length target, we obtain 1.4×10^{11} interactions. Therefore, one obtains 2.2-22$\times 10^7$ Hybrid Primakoff events at 100% efficiency. We assume now a 50% accelerator operation efficiency. We also estimate a global 10% average detection efficiency over all decay channels for tracking, γ detection, η acceptance and identification, trigger acceptance, global geometric acceptance, and event reconstruction efficiency. All these effects give a global efficiency of 5%. Therefore, we may expect to observe a total of 1.1-11$\times 10^6$ Hybrid decays in all decay channels. For example, following the Close and Page predictions, we may expect 24% in πf_1, 2-8% in $\pi\rho$, 67% in $b_1\pi$, 0-4% in $\eta\pi$, 0-4% in $\eta'\pi$, etc.

For 2, 2.5, 3.0 GeV mass Hybrids, the number of useful events decreases by factors of 6, 25, and 100, respectively. But even in these cases, assuming again a global 5% efficiency, that represents very interesting potential samples of 1.8-18$\times 10^5$, 4.4-44$\times 10^4$, and 1.1-11$\times 10^4$ Hybrid meson detected events, with masses 2, 2.5, and 3 GeV respectively.

COMPASS can study hybrid meson candidates near 1.4, 1.6, 1.9 GeV produced by the Primakoff and Diffractive processes. COMPASS should also be sensitive to pionic hybrids in the 2-3 GeV mass range. We may obtain superior statistics for hybrid states if they exist, and via a different production mechanism, without possible complication by hadronic final state interactions. We may also get important data on the different decay modes for this state. The observation of these/other hybrids in different decay modes and in a different experiment would constitute the next important step following the evidence so far reported.

COMPASS provides a unique opportunity to investigate QCD hybrid exotics, via diffractive and Primakoff production. Taking into account the very high beam intensity, fast data acquisition, high acceptance and good resolution of the COMPASS setup, one can expect from COMPASS the highest statistics and a 'systematics-free' data sample that includes many tests to control possible systematic errors. Intercomparisons between COMPASS and other experiments with complementary methodologies should allow fast progress on understanding hybrid meson structure, and on fixing the systematic uncertainties.

3. Plan of Operation:

COMPASS studies hybrid meson structure via the scattering of high energy pions from "photon" and "Pomeron" targets. We use 100-280 GeV beams (μ, π) and magnetic spectrometers and calorimeters to measure the complete kinematics of pion-photon and pion-Pomeron hybrid production reactions. Initial COMPASS set up runs are scheduled for Summer 2000. COMPASS will then study "proton spin" using a muon beam to measure the gluon polarization, and Hybrid meson structure using a pion beam. These programs will benefit from high statistics, excellent beam focusing and momentum analysis, and dedicated low background runs. We will analyze pion and muon test run data, we will carry out simulation studies, and we will plan and analyze dedicated COMPASS runs to maximize quality results.

More accurate physics and trigger simulations are required using the new C-programmed COMPASS GEANT package. This code should include the updated experimental setup, trigger and the DAQ schemes, accurate magnetic field mapping, and event reconstruction. We work on this package, incorporating a Primakoff hybrid meson structure event generator. We develop COMPASS event reconstruction algorithms, and test them on GEANT simulated events.

For the COMPASS Hybrid meson structure effort, we need to plan, construct and implement all hardware and software for the trigger. We will prepare the COMPASS pion-photon Primakoff trigger system by the following phases: (1) continue to investigate the hodoscope matrix energy loss and multiplicity 3 triggers, mentioned above, via MC simulations, (2) refine our MC trigger simulations using COMGEANT, (3) construct the trigger hardware, including an upgrade of the existing CEDARS Cherenkov beam PID detector, scintillation hodoscopes, fast signal summing circuitry, mechanical supports, etc., (5) install the system at CERN, (6) set up the trigger detectors and electronics in the COMPASS muon beam, (7) take preliminary data with muons, writing event reconstruction algorithms, and checking trigger performance, (8) use it for running the COMPASS hybrid meson structure experiment with pion beams.

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